Effective Strategy for MPPT in PV/Wind Hybrid Electric Power System Interconnected with Electrical Utility Grid

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Abstract- This paper focusing in modeling and simulation of incremental conductance(inc. cond)algorithm of maximum power point tracking (MPPT) method used in photo voltaic/wind hybrid electric power system inter connected to the electric utility. PV/wind HEPS, taking into account all radiation, temperature, variation of wind speed and load demand. The resultant system is capable of tracking MPPs accurately and rapidly without steady-state oscillation, and also, its dynamic performance is satisfactory. The incremental conductance algorithm is used to track MPPs, because it performs precise control under rapidly changing atmospheric conditions. MAT LAB and SIMULINK were employed for simulation studies. Simulation results indicate the feasibility and improved functionality of the system. The main objective of this paper is maximizing the PV output power and wind energy system (WES) output power independently by tracking the maximum power on every operating condition by using MPPT technique and interconnected to utility grid.

Key Words – incremental conductance (inc cond), maximum power point(MPP), hybrid electric power system(HEPS) wind energy system(WES).

I.　INTRODUCTION

As energy demands around the world increase, the need for a renewable energy sources that will not harm the environment has been increased. Some projections indicate that the global energy demand will almost triple by 2050[1]. Renewable energy sources currently supply somewhere between 15% and 20% of total world energy demand. PV and Wind Energy System, WES, are the most promising as a future energy technology. A 30% contribution to world energy supply from the renewable energy sources by year 2020 [2] as in would reduce the energy related CO_2 emission by 25 %.

With their advantages of being abundant in nature and nearly non pollutant, renewable energy sources have attracted wide attention. Wind power is one of the most promising clean energy sources since it can easily be captured by wind generators with high power capacity. Photovoltaic (PV) power is another promising clean energy source since it is global and can be harnessed without using rotational generators. In fact, wind power and PV power are complementary to some extent since strong winds are mostly to occur during the nighttime and cloudy days whereas sunny days are often calm with weak winds . Hence, a wind–PV hybrid generation system can offer higher reliability to maintain continuous power output than any other individual power generation systems. In those remote or isolated areas, the stand-alone wind–PV hybrid generation system is particularly valuable and attractive.

To maximize a photovoltaic (PV) and wind energy system's output power, continuously tracking the maximum power point (MPP) of the system is necessary. Dr.Abu Tariq[3] presented a simulink based modeling simulation and performance evaluated of an MPPT for maximum power generation on resistive load. Sachin gain and vivek agarwal[4] presented A single grid connected inverter topology with MPPT of standalone PV system. Owin,L.A nyakoe [5] presented a MPPT techniques in wind power generation. Eftichios[6] design a MPPT system for wind energy conversion application. Debra J. Lew et. al [7] presented a designed hybrid wind/photovoltaic systems, using batteries for households in Inner Mongolia using the optimization program HOMER and model Hybrid2. R. Chedid and Saifur Rahman [8] introduced a decision support technique for design of PV/WES HEPS. Yarú Najem and Méndez Hernández [9] simulation models of the PV/WES HEPS verified with measured data in a real system located near the department efficient energy conversion of the Kassel University. But most of the researches haven't modeling and simulation of PV/Wind HEPS techniques by using MPPT at the point of connection of operation in details. So, The main objective of this paper is maximizing the PV output power and wind output power independently by tracking the maximum power on every operating condition by using MPPT technique and interconnected to utility grid.

A.　MPPT METHODS

MPPT algorithms are necessary in renewable energy sources to gain maximum power and efficiency. There is a large number of algorithms that are able to track MPPs. Over the past decades many methods to find the MPP have been developed

and published. These techniques differ in many aspects such as required sensors, complexity, cost, range of effectiveness, convergence speed, correct tracking when irradiation and/or temperature changes, hard ware needed for the implementation. Having a curious look at the recommended methods, P&O and incremental conductance are the algorithms that were in center of consideration because of their simplicity and ease of implementation[10]. However the P&O algorithm cannot compare the array terminal voltage with actual MPP voltage, since the change in power is only considered to be a result of array terminal voltage perturbation. As a result, they are not accurate enough because they perform steady state oscillation, which consequently waste the energy [11]. By minimizing the perturbation step size, oscillation can be reduced, but a smaller perturbation size slows down the speed of tracking MPPs. Thus, there are some disadvantages with these methods, where they fail under rapidly changing atmospheric conditions [12]. On the other hand, some MPPTs are more rapid and accurate and, thus, more impressive, which need special design and familiarity with specific subjects such as fuzzy logic [13] or neural network methods. MPPT fuzzy logic controllers have good performance under varying atmospheric conditions and exhibit better performance than the P&O control method; however, the main disadvantage of this method is that its effectiveness is highly dependent on the technical knowledge of the engineer in computing the error and coming up with the rule-based table. It is greatly dependent on how a designer arranges the system that requires skill and experience. A similar disadvantage of the neural network method comes with its reliance on the characteristics of the PV array that change with time, implying that the neural network has to be periodically trained to guarantee accurate MPPs.
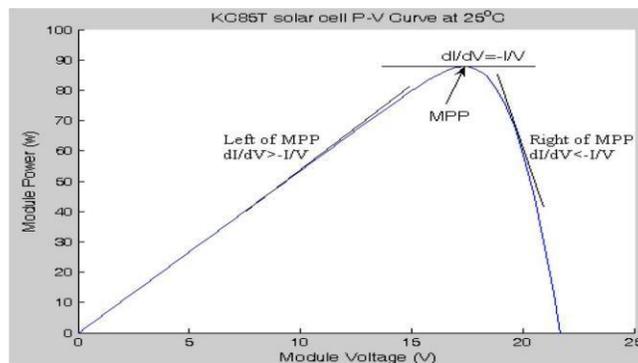

Fig. 1 Basic idea of the IncCond method on a *P−V* curve of a solar module

The IncCond method is the one which overrides over the aforementioned drawbacks. In this method, the array terminal voltage is always adjusted according to the MPP voltage. It is based on the incremental and instantaneous conductance of the PV module [14],[15].

Fig. 1 shows that the slope of the PV array power curve is zero at the MPP, increasing on the left of the MPP and decreasing on the right-hand side of the MPP. The basic equations of this method are as follows [16]

$$\frac{dI}{dV} = -\frac{I}{V} \quad \text{at MPP} \qquad (1)$$

$$\frac{dI}{dV} > -\frac{I}{V} \quad \text{left of MPP} \qquad (2)$$

$$\frac{dI}{dV} < -\frac{I}{V} \quad \text{right of MPP} \qquad (3)$$

Where, *I* and *V* are the PV array output current and voltage respectively. The left-hand side of the equations represents the IncCond of the PV module, and the right- hand side represents the instantaneous conductance. From (1)–(3), it is obvious that when the ratio of change in the output conductance is equal to the negative output conductance, the solar array will operate at the MPP. In other words, by comparing the conductance at each sampling time, the MPPT will track the maximum power of the PV module. The accuracy of this method is proven in, where it mentions that the IncCond method can track the true MPPs independent of PV array characteristics. Incremental conductance algorithm is based on the fact that the slope of the curve power vs. voltage (current) of the PV module is zero at the MPP, positive (negative) on the left of it and negative (positive) on the right. By comparing the increment of the power vs. the increment of the voltage (current) between two consecutives samples, the change in the MPP voltage can be determined.

Also, Roman *et al.* [17] described it as the best MPPT method, where it has made a comprehensive comparison between P&O and the IncCond method with boost converter and shows that the efficiency of experimental results is up to 95%. In [18], efficiency was observed to be as much as 98.2%, but it is doubtful of the IncCond method reliability issues due to the noise of components. Some modifications and reformations were proposed on this method so far, but since this method inherently has a good efficiency, the aforementioned amendments increase the complexity and cost of the system and there was no remarkable change in system efficiency.

B. SELECTING A PROPER METHOD

The disadvantage of the perturb and observe method to track the peak power under fast varying atmospheric condition is overcome by IC method [19]. The IC can determine that the MPPT has reached the MPP and stop perturbing the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between dI/dV and –I/V. This relationship is derived from the fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP. This algorithm has advantages over P&O in that it can determine when the MPPT has reached the MPP, where P&O oscillates around the MPP. Also, incremental conductance can track rapidly increasing and decreasing irradiance conditions with higher accuracy than perturb and observe method.
The respective algorithm of incremental conductance MPPT method is shown below.

Inputs: $V(t)$, $I(t)$, $V(t-\Delta t)$, $I(t-\Delta t)$
$P(t)$ & $P(t-\Delta t)$ calculated from the inputs

$\Delta V = V(t) - V(t-\Delta t)$
$\Delta P = P(t) - P(t-\Delta t)$
$(\Delta I = I(t) - I(t-\Delta t))$

$\Delta V/\Delta P=0$
$(\Delta I/\Delta P=0)$

NO

$\Delta V/\Delta P>0$
$(\Delta I/\Delta P<0)$

NO   YES   YES

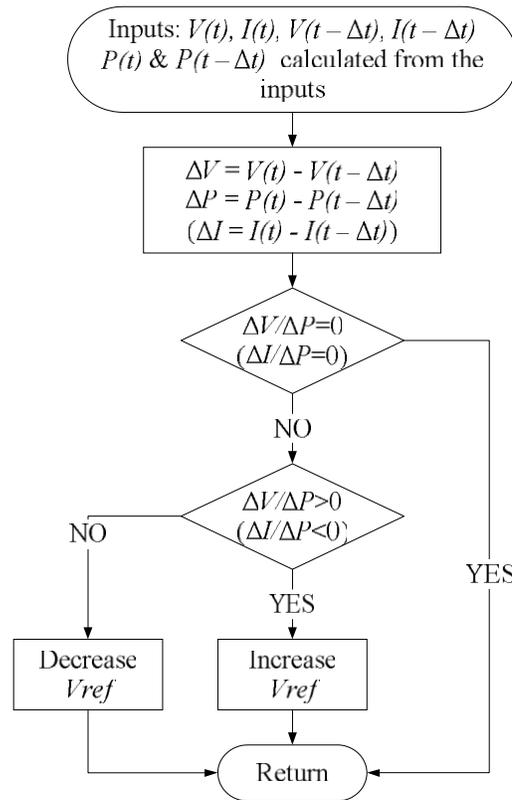Decrease *Vref*   Increase *Vref*

Return

Fig 2.inc cond algorithm

The above algorithm shows that, how the controller follows the mathematical method to generates the required pulses to track the maximum power from the system.

II . SYSTEM MODEL

The system model shown in fig. represents PV/Wind HEPS connected to a 50 Hz, 22 kV Utility grid. PV system connected to utility grid through a DC/DC boost converter, DC/AC inverter, LC filter and step-up transformer. WTG connected to utility grid through back to back converter, LC filter and step-up transformer. The load connected to 22kV Bus through a step-down transformer. The power obtained from PV system is applied to an IGBT's inverter. The task of the boost DC/DC converter drains the power from the PV system and feed the DC link capacitor with a maximum power point tracker. The MPPT controls incremental current and voltage magnitudes. The variables which will be sensed for the controller of PV system are PV solar cell array current i_{pv}, DC link voltage v_{dcp}, inverter filter output currents $i_{fva}, i_{fvb}, i_{fvc}$, load phase currents I_{La}, I_{Lb}, I_{Lc} and load phase voltages V_a, V_b, V_c. The variables which will be sensed for the controller of WTG are DC link voltage, V_{dcw}, inverter filter output currents I_{invaw}, I_{invbw}, I_{invcw}, load currents I_{La}, I_{Lb}, I_{Lc} and load phase voltages V_a, V_b, V_c. To provide the active filtering function, the filter output currents are controlled to ensure that the utility line currents and load current are sinusoidal and in phase with the phase voltage. The filter out put currents are also controlled to pass power are also controlled to pass power from the PV/Wind HEPS to the load and/or utility grid. The DC link voltage V_{dcpv} and V_{dcpw} must be controlled to be higher than the peak line voltage of the utility grid. The proposed system control scheme for the wind system uses VSC controller to synchronize the wind form with grid by using d-q method. The load currents and load voltages are sampled and transformed into the two-axis αβ-

coordinate system and then into the rotating d-q coordinate system. d-q method uses the park transformation, as in (1) to generate two orthogonal rotating vectors α and β from the three-phase vectors a, b and c. This transformation is applied to the voltages and currents and so the symbol x is used to represent voltage or current.

$$\begin{bmatrix} X_O \\ X_\alpha \\ X_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} \qquad -------------------(4)$$

The instantaneous active and reactive powers p and q are calculated from the transformed voltage and current. Then the reference compensating currents have been determined as in eqn.

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & V_{-\beta} \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} P_{PV} + P_W \\ Q_{PV} + P_W \end{bmatrix} \qquad ------------------------(5)$$

In a balanced three-phase system with linear loads, the instantaneous real power p and imaginary power q are constant and equal to the three-phase conventional active power P3Φ and reactive power Q3Φ respectively. So, the inverse park transformation is applied to i_α^* and i_β^* and this gives output currents in standard three-phase form as in (6).

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} \qquad ------------------------ (6)$$

There are two modes of operation:
• **Mode 1:** When the generated power from PV/Wind HEPS is lower than the load demand then the deficit power will be supplied from the utility grid. Presumably, the power factor will be within the allowed limits.
• **Mode 2:** When the generated power from PV/Wind greater than the load demand then the surplus power will be transmitted to the utility grid. In this condition, the power factor of the ac source will deteriorate.
The respective active power and reactive power results will see under simulation results part.
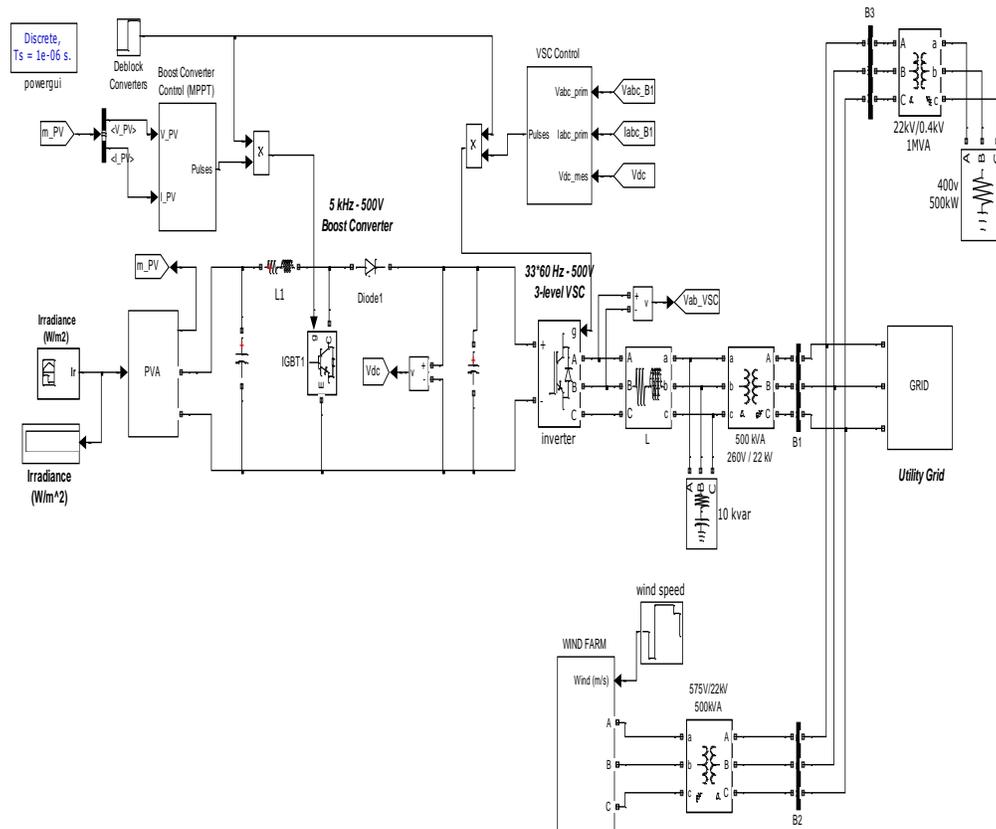

Fig.3 Power and control Circuit of PV/WTG HEPS Interconnected with utility grid to Feed the Load
In the above figure shown respective PV/WTG HEPS Interconnected with utility grid to Feed the Load. The wind energy system is directly shown in the above figure that respective control circuit model shown in below.
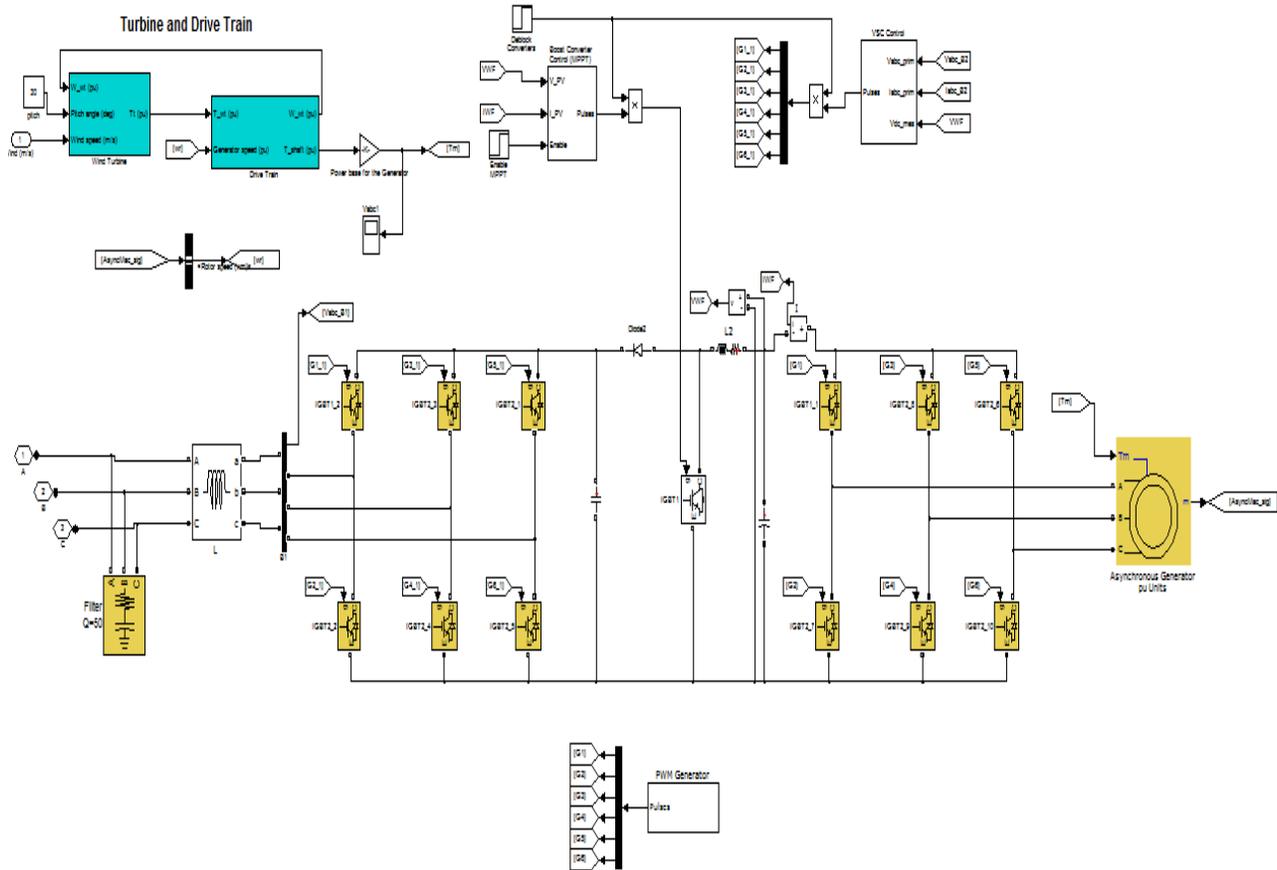Control module of wind energy system:

Fig4.control module of wind turbine

The wind turbine control figure consists of turbine and drive train to produce mechanical torque. In this model asynchronous machine producing negative torque to acts as a induction generator. In this module VSC controller is very important to synchronize the wind turbine with the grid to reduce the harmonics in the system and also synchronize the phase sequence of grid and wind turbine. MPPT controller is produce the required pulse signals to track the maximum power. The respective resultant figures will show under simulation results.

III. SIMULATION RESULTS
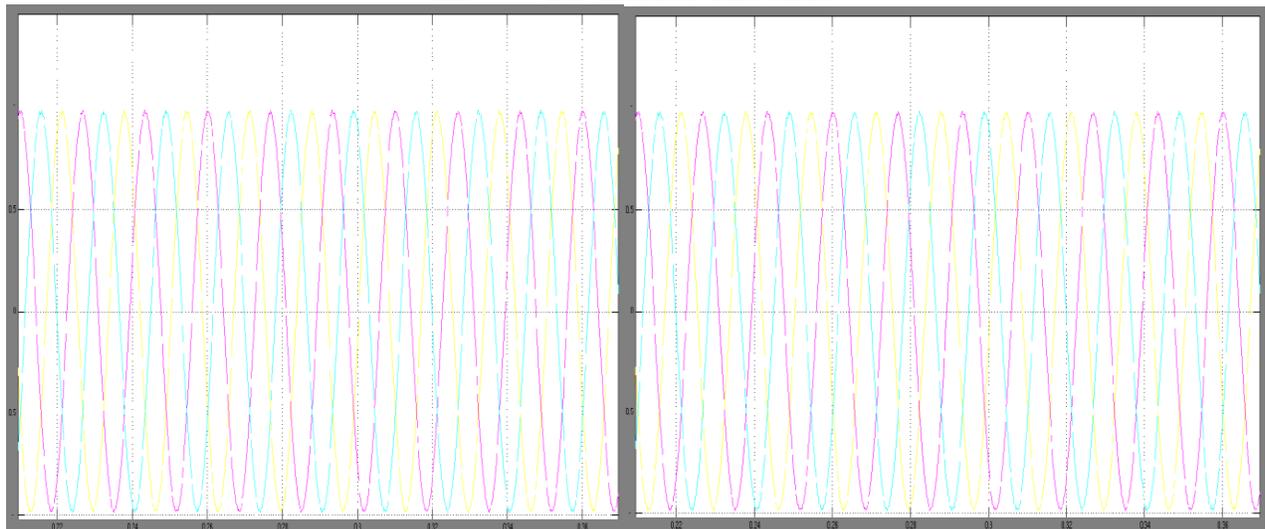
Fig 5 simulated voltage wave form of PV at   p.c.c (point of common connection)   Fig 6 simulated voltage wave form of WIND at p.c.c
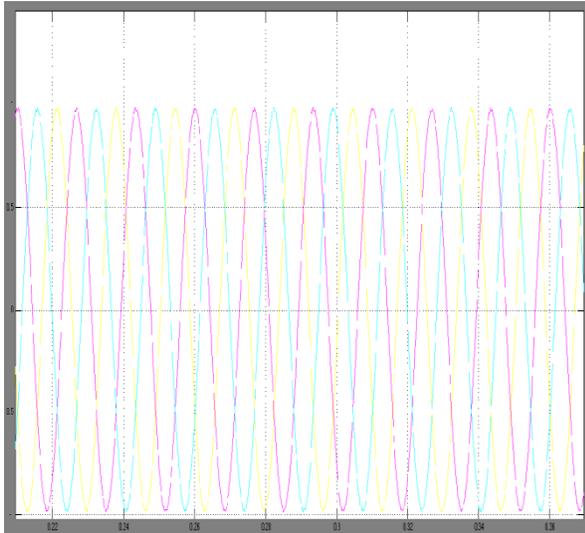
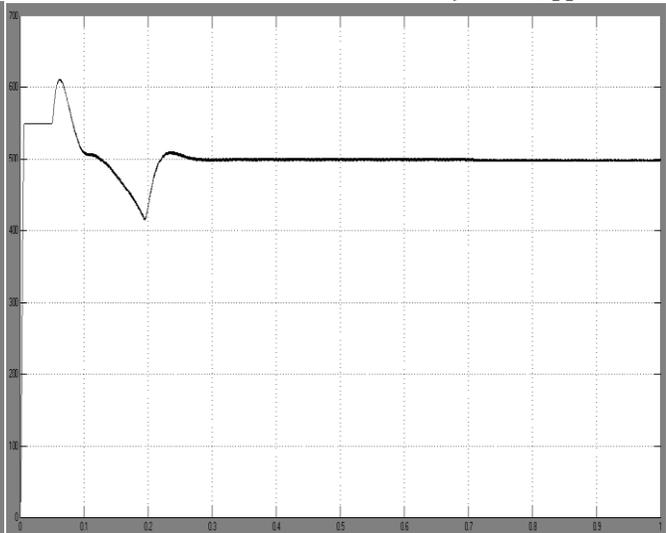Fig 7 simulated voltage wave form of HEPS at p.c.c waveform at p.c.c

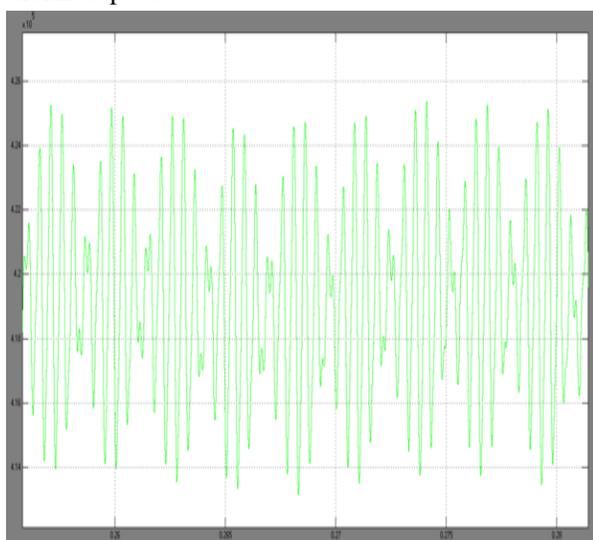Fig 8 simulated MPPT controller of output v_{dc}

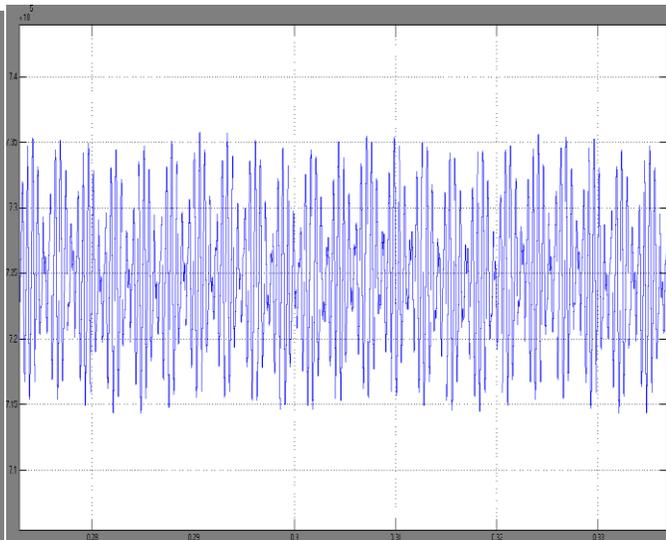Fig 9 simulated power wave form of PV at p.c.c

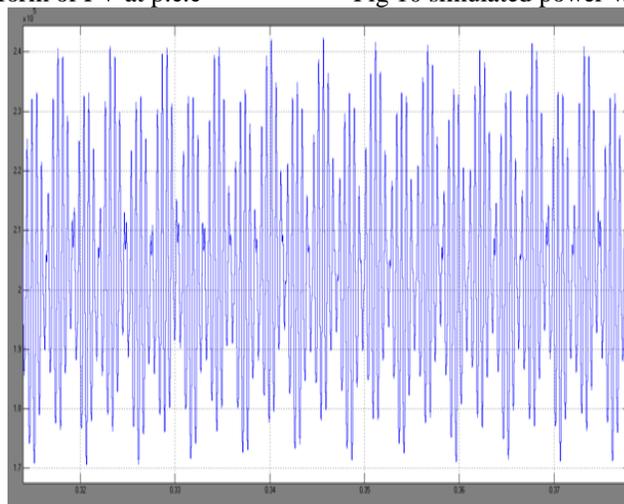Fig 10 simulated power wave form of HEPS at p.c.c

Fig 11 simulated power wave form of WIND at p.c.c

The power circuit of Fig.3 shows an overview of the power and control circuit of the proposed MPPT   techniques   of PV/WTG interconnected with Utility grid. The Fig.4 has shows the WIND turbine control circuit model. It has been simulated using Matlab /simulink and that resultant waveforms are given respective outputs of system. In that fig. 5, 6 and

7 shows respective simulated output voltages from PV, WIND and HEPS. The proposed model has given a purely sinusoidal controlled voltage at grid terminals. Fig8 shows the simulated MPPT controller D.C voltage output waveform and it maintains the constant voltage of 500v for different irradiation levels. The figures 9,10 and 11 gives different outputs of power for independent systems. The PV system gives the power $4.935e10^5$ W generated using MPPT technique. Similarly fig 10 and 11 shows the WIND and HYBRID system have $2.125e10^5$ and $7.236e10^5$ W power generated.

IV. Conclusion

The results obtained from above discussion, the following are the salient conclusions. That can be drawn from this paper Designed the optimal MPPT controller and designed the control circuit for the PV/WIND system converters for all radiation and wind speed and that have been studied and proposed. Improving the maximum power by using MPPT algorithm independently for the different systems and connected to the grid. A novel of PV/Wind HEPS interface with electrical grid for solving modeling and simulation problems by using MATLAB /SIMULINK environment have been proposed. Detailed modeling simulation of MPPT controller for the PV/WIND system converters was designed and **investigating the active and reactive power results while connecting** PV/Wind HEPS interface with electrical grid.

References
[1] H. H. El-Tamaly et. al. ,"Design and Control Strategy of Utility Interfaced PV/WTG Hybrid System", The 9th East Power System conference,MEPCON'2003,Minoufiya University, Faculty of Eng., Shebin El-Kom, Vol. 2, Dec. 16-18, 2003.
[2] International Energy agency report, "Key Issues in Developing Renewable".
[3] 3.Dr.Abu Tariq " simulink based modeling simulation and performance evaluated of an MPPT for maximum power generation on resistive load" International conference on environmental science and technology IPCBEE vol.6,april 2011.
[4] Sachin gain and vivek agarwal[4] " A single grid connected inverter topology with MPPT of stand alone PV system" IEEE transaction on power electronics vol.22,no.5,September 2007.
[5] Owin,L.A nyakoe, G.N and Kibicho " MPPT techniques in wind power generation" .
[6] Eftichios koutroulis" design a MPPT system for wind energy conversion application" IEEE transaction on industrial electronics vol.53,no.2,april 2006.
[7] Debra J. Lew et. al., "Hybrid Wind photovoltaic Systems for Households in Inner Mongolia", International Conference on Village Electrification Through Renewable Energy, New Delhi, 3-5 March1997.
[8] R. Chedid and Saifur Rahman, "A Decision Support Technique For the Design of Hybrid Solar-Wind Power Systems", IEEE Trans. on Energy conversion, Vol. 13, No. 1, March 1998, pp. 76-83.
[9] Yarú Najem and Méndez Hernández, "Assessment of the Energy Production by Means of the Clearness Index in Hybrid Systems", 2nd European PV-Hybrid and Mini-Grid Conference, Thursday, 25th Sept. and Friday, 26th Sept. 2003, Kassel, Germany.
[10] Hairul Nissah Zainudin " Comparison Study of Maximum Power Point Tracker Techniques for PV Systems" *Center of Foundation in Sciences, CyberjayaUniversity College of Medical Sciences,Cyberjaya, Selangor, Malaysia*.
[11] T. Esram and P. L. Chapman, ―Comparison of photovoltaic array maximum power point tracking techniques,‖ IEEE Trans. Energy Convers., vol. 22, no. 2, pp. 439–449, Jun.2007.
[12] K. H. Hussein, I. Muta, T. Hoshino, and M. Osakada,―Maximum photovoltaic power tracking: An algorithm for rapidly changing atmospheric conditions,‖ Proc. Inst. Elect. Eng.—Gener, Transmits. Distrib., vol. 142, no. 1, pp. 59–64, Jan. 1995.
[13] T.-F.Wu, C.-H. Chang and Y.-H. Chen, ―A fuzzy-logic- controlled singlestage converter for PV-powered lighting system applications,‖ IEEE Trans. Ind. Electron., vol. 47, no. 2, pp. 287–296, Apr. 2000.
[14] B. Liu, S. Duan, F. Liu, and P. Xu, ―Analysis and improvement of maximum power point tracking algorithm based on incremental conductance method for photovoltaic array,‖ in Proc. IEEE PEDS, 2007, pp. 637–641.
[15] Y.-C. Kuo, T.-J. Liang and J.-F. Chen, ―Novel maximum-power-point tracking controller for photovoltaic energy conversion system,‖ IEEE Trans. Ind. Electron, vol. 48, no.3, pp. 594–601, Jun. 2001.
[16] D.Sera, T.Kerekes, R. eodorescu, and F.laabjerg, Improved MPPT Algorithms for Rapidly Changing Environmental Conditions. Aalborg, Denmark: Aalborg Univ. /Inst. Energy Technol., 2006.
[17] E. Roman, R. Alonso, P. Ibanez, S. Elorduizapatarietxe, and D. Goitia, ―Intelligent PV module for grid-connected PV systems, IEEE Trans.Ind Electron., vol. 53, no. 4, pp.1066–1073, Jun. 2006.
[18] H. H. El-Tamaly and Adel A. El-baset, "Computer Modeling and Simulation of Wind Energy System Connected to Utility Grid" Proceedings on 2004 International Conference on Electrical, Electronic and Computer Engineering ICEEC'04,5-7 September2004, Cairo, Egypt.
[19] Hairul Nissah Zainudin " Comparison Study of Maximum Power Point Tracker Techniques for PV Systems" *Center of Foundation in Sciences, CyberjayaUniversity College of Medical Sciences,Cyberjaya, Selangor, Malaysia*.